BIAXIAL FLEXURAL FATIGUE RESPONSES OF CIRCULAR CONCRETE PLATES

G. Zi[1*†] and J. Kim[1]

[1]*School of Architectural, Civil, and Environmental Engineering, Korea University, Korea*

ABSTRACT

Concrete structures such as pavement, panel, thin-walled concrete dome, and large slab are subjected to repeated loadings in service. These structural components are exposed to a biaxial stress. The objective of this work is to study the flexural fatigue responses of circular concrete plates, where the stress state is biaxial during the test, by different two test methods: the centrally loaded round panel test (ASTM C 1150) and the biaxial flexure test (BFT). The biaxial fatigue responses of circular plates are compared with uniaxial one obtained by four-point bending test. Test results show that the fatigue strength of ASTM C 1550 is higher than that of biaxial flexure test. It is observed that there are no substantial differences in flexural fatigue response between under biaxial and uniaxial stress states.

Keywords: Biaxial strength, biaxial flexure test, fatigue, plate, concrete.

1. INTRODUCTION

Concrete plate structures such as concrete pavements and slabs are subjected to repeat fatigue loadings which produce the cracks in the concrete components. For structural design consideration, various models to predict the fatigue strength of concrete have been suggested, such as ACI Committee 215 (ACI, 1992), JSCE (JSCE, 2007), CEB-FIP Model code 1990 (CEB-FIP, 1993). These approaches for fatigue design of concrete structures were developed based on experimental data mostly obtained under uniaxial compressive load, or uniaxial flexural load. However, the aforementioned plate structures were exposed to biaxial stress conditions. Therefore, it is reasonable to use the fatigue models derived from the biaxial stress condition for the fatigue design of these structures.

In order to estimate the flexural fatigue strength of concrete under biaxial stress states, two test methods are currently available: the centrally loaded round panel test (ASTM C 1550, 2008), and the biaxial flexure test (BFT) (Zi et al. 2008), as shown in Figure 1. Two test methods use a circular plate and yield the maximum biaxial flexural tensile stress on the opposite side of the plate underneath the loading fixture (Kim et al. 2012).

* Presenter: Email: g-zi@korea.ac.kr

† Corresponding author: Email: g-zi@korea.ac.kr

In this paper, the biaxial flexural fatigue response of concrete is experimentally studied, by using ASTM C 1550 and the biaxial flexure test. The fatigue behaviors in biaxial flexural stress are compared with those obtained from the uniaxial one.

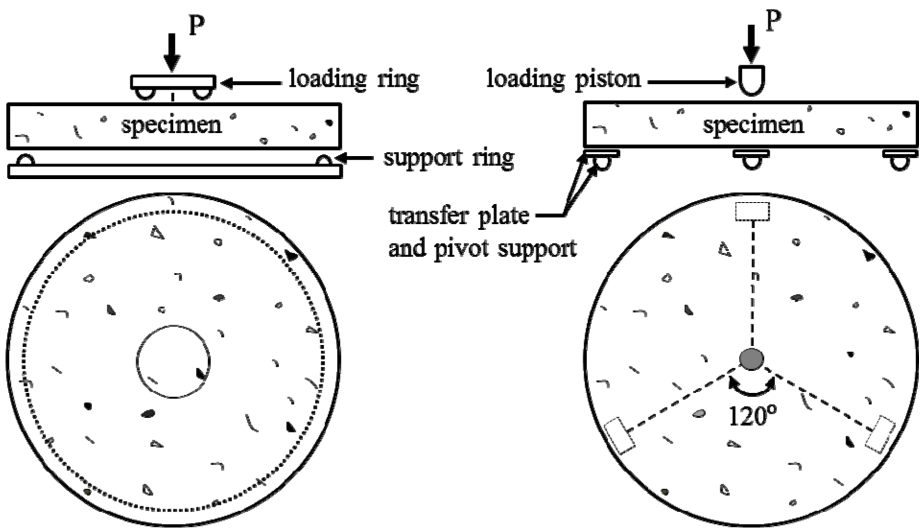

Figure 1: Schematic of the set-up for (a) the biaxial flexure test and (b) ASTM C 1550.

2. EXPERIMENT

2.1. Materials and test specimens

The experimental program was designed to study the fatigue response of circular concrete plates on different biaxial test methods as well as stress conditions. For this study, 48×420 mm (thickness× diameter) circular plates and 48×48×244 mm beam specimens were used for monotonic and fatigue tests. All beam and plate specimens were cast from the same batch of concrete and the mix proportion is provided in Table 1. In order to minimize the variation in compressive strength, the test specimens were cured in a water bath for 90 days until the testing date. The compressive strength was 71.2 MPa at 90 days.

Table 1: Mix proportion of the concretes

W/C (%)	S/a (%)	Unit weight(kg/m^3)			
		W	C	S	G
42	49	170	405	866	934

2.2. Test methods

The monotonic and fatigue testing were conducted by using the ASTM C 1550, the biaxial flexure test and four-point bending test. The fatigue tests were carried out with load control at a frequency of 10 Hz. The flexural fatigue tests for each test method were conducted under three stress levels (*S*), i.e. 90 %, 80 % and 70 %, of the static flexural strength of concrete from each test method. At each stress level, three specimens were tested.

Strains were measured to verify the biaxial stress state at the center of tensile surface of the circular plate, and to evaluate the deformability according to the number of load cycles. Two strain gages with a 60 mm gauge length were used for the strain measurements. All tests were conducted using a 100 kN servo-hydraulic actuator and dynamic data logger was used to record all measurements. Detailed information about the test setup of the biaxial flexure test method can be found in Kim et al. (Kim et al. 2013).

3. RESULTS AN DDISCUSSIONS

Under monotonic loading conditions, the fracture strengths of the four-point bending test, ASTM C 1550 and biaxial flexure test are summarized in Table 2. The results show that biaxial flexural strengths obtained from ASTM C 1550 and biaxial flexure test are higher than those for the four-point bending test, and the biaxial strength measured by ASTM C 1550 is greater than the strength by biaxial flexure test.

Table 2: Monotonic test results obtained from ASTM C 1550, biaxial flexure test and four-point bending test.

test methods	ASTM C 1550	biaxial flexure test	four-point bending test
mean strength [MPa]	12.73	9.68	7.43
S.D [MPa]	0.57	0.39	0.13
c.o.v [%]	5	4	2

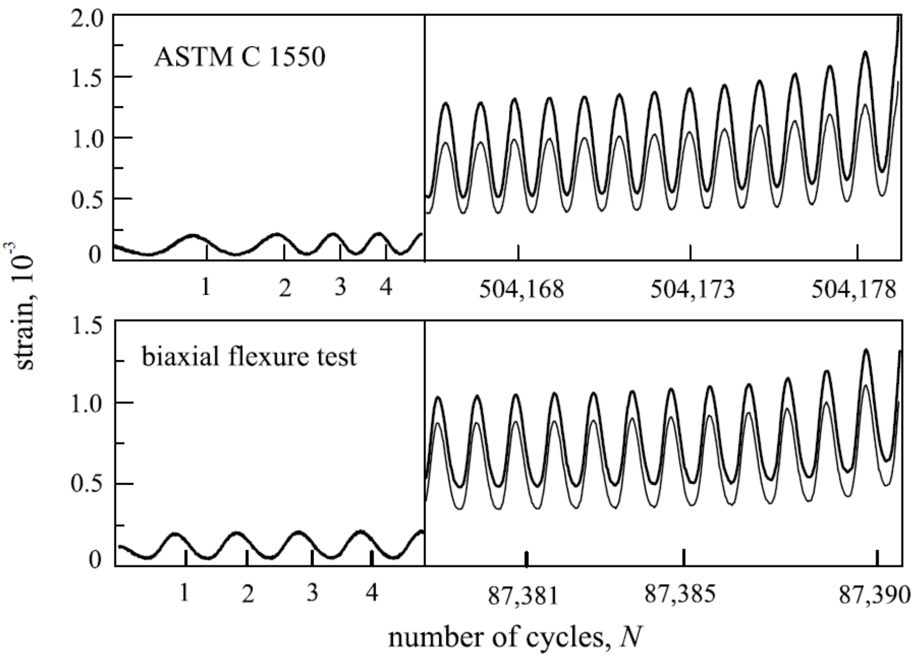

Figure 2: Strain history in the fatigue test for (a) the ASTM C 1550 and (b) biaxial flexure test (*S*=80 %).

Figure 2 shows the measured tensile strain at the center of the bottom surface of a ASTM C 1550 and biaxial flexure test specimen subjected to S=0.8, against the number of loading cycles. It was verified that the strain distribution was biaxially uniform at the beginning of the fatigue tests. However, two strain measurements began to show discrepancy, as the number of cycles increased. This can be attributed to the formation and growth of microcracks in a preferential direction. This observation indicates that the stress state leading to the failure was not equibiaxial.

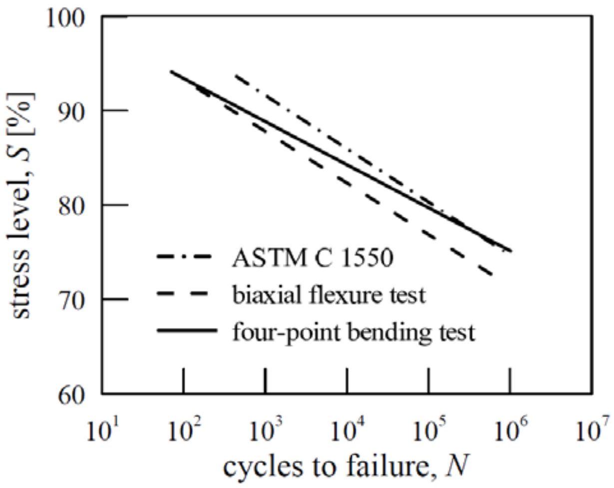

Figure 3: *S-N* fatigue curves obtained from (a) ASTM C 1550, (b) biaxial flexure test, and (c) four-point bending test.

Figure 3 shows the *S-N* curves constructed using the best-fit curves of experimental data from this study. The fatigue life of all of the specimens for the three test methods slightly increased with a decrease in stress level. The figure shows that the curve obtained from the four-point bending tests lies between the curves of biaxial flexure test and ASTM C 1550, with a different slope than that of the other two test methods. Considering the large scatter in the test data, the difference in the aforementioned fatigue strengths estimated by the three best-fit curves seems to be negligible, which, in turn, suggests that the effect of stress state on the tensile fatigue strength is not as significant. Therefore, the test results indicate that the biaxial flexural fatigue life can be determined or predicted from the fatigue model obtained by rupture strength.

4. CONCLUSIONS

The stress condition at the center of the tensile surface of circular plates was biaxial at the beginning of the fatigue tests. However, the stress state leading to the failure of plates was not biaxial. The biaxial flexure test results are parallel to those of ASTM C 1550, but the fatigue strength of ASTM C 1550 is higher than that of the biaxial flexure test, for any given number of cycles. There is no significant difference in flexural fatigue response between under biaxial and uniaxial stress states. Hence, the uniaxial fatigue strength of concrete may be adopted for the design of concrete components subjected to biaxial fatigue loading.

5. ACKNOWLEDGMENTS

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